Space Radiation Effects on Microelectronics

Presented by the Radiation Effects Group

Section 514
Sammy Kayali, Section Manager

Radiation Effects in Space

Radiation Is a Discriminating Environment for JPL Missions

Dealing with Potential Radiation Problems Is Critical for Mission Success

- Complex problem, made worse by evolving technology
- Past mission performance illustrates how JPL can be successful in space
- Learning from previous mistakes and oversights is also important

This Course Is Intended to Increase Awareness of Radiation Issues

- Attended by designers and spacecraft operational personnel
- Limited in scope
  - Not intended to make everyone an expert
  - Provides basic information and points of contact

Examples of Radiation Problems in Spacecraft

Special Redesign of 2901 Microprocessor for Galileo

- Problem identified during design and evaluation
- Potential "show stopper" for Galileo mission

Resets in Hubble Space Telescope after Upgrade in 1996

- Caused by transients from optocouplers
- Occurred when spacecraft flew through South Atlantic anomaly

Failures of Optocouplers on Topex-Poseidon

Resets in Power Control Modules on Cassini

High Multiple-Bit Error Rate in Cassini Solid-State Recorder

Available Resources at JPL

Laboratory Facilities and Test Technology

- Cobalt-60 test cell
- Frequent off-site tests at accelerators

Experienced, Knowledgeable Personnel

- Aware of project needs
- Continual evaluation and modeling of new technologies

RADATA Data Base

Reports and Technical Papers

Key Contacts for Radiation Effects Issues

Allan Johnston, Acting Group Supervisor

Leif Scheick

Gary Swift

John Conley

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Steve McClure

Larry Edmonds

Sumit Shah (RADATA data base)

Course Outline

Introduction

Overview of Radiation Environments

Recoverable Single-Event Upset Effects

Non-Recoverable Single-Event Upset Effect

Total Dose Effects

Displacement Damage and Special Issues for Optoelectronics

Summary

Section II: Overview of Radiation Environments

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Radiation Environments

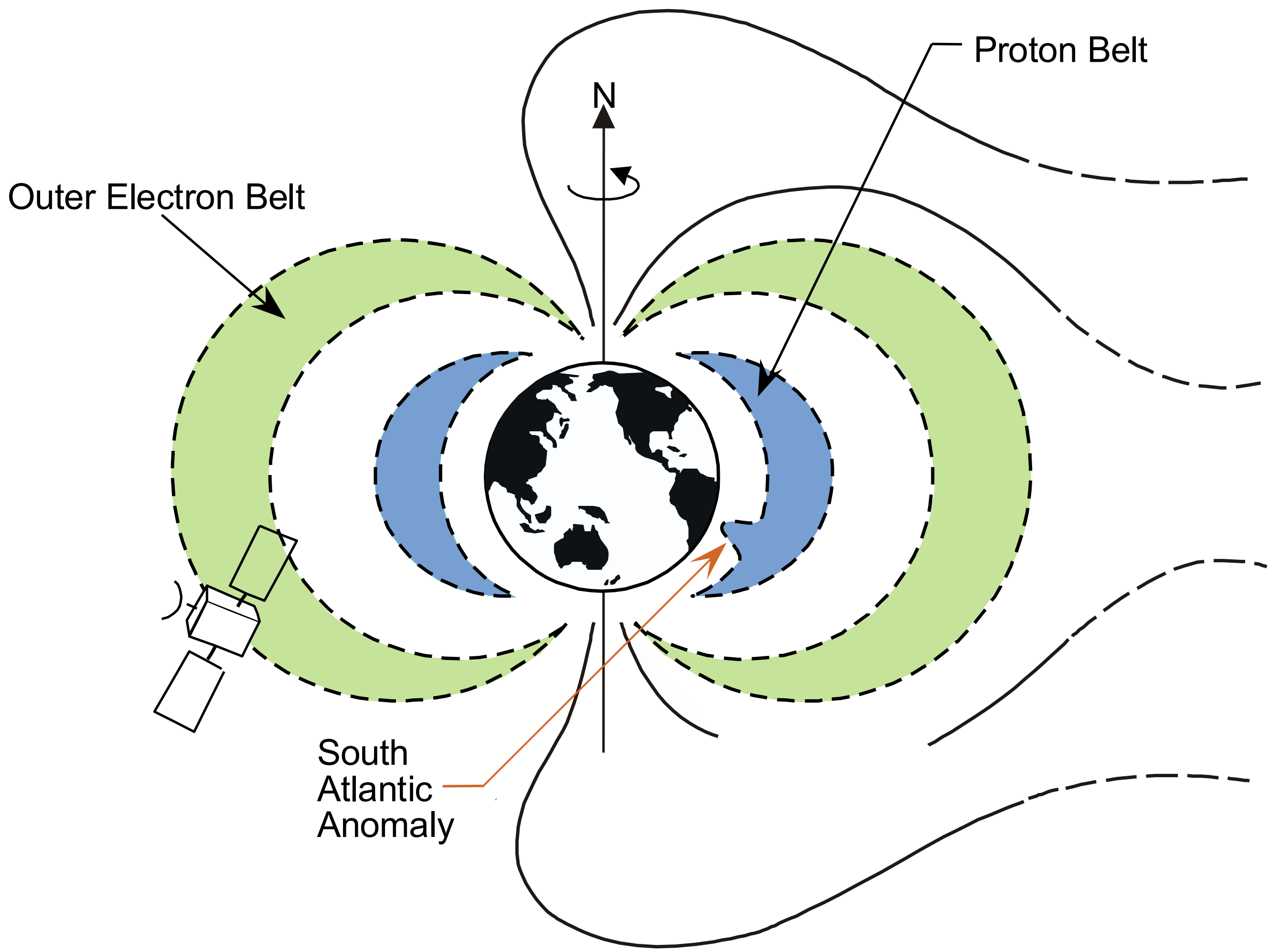
Energetic Particles Causing Single-Event Upset

- Galactic cosmic rays
- Cosmic solar particles (heavily influenced by solar flares)
- Trapped protons in radiation belts

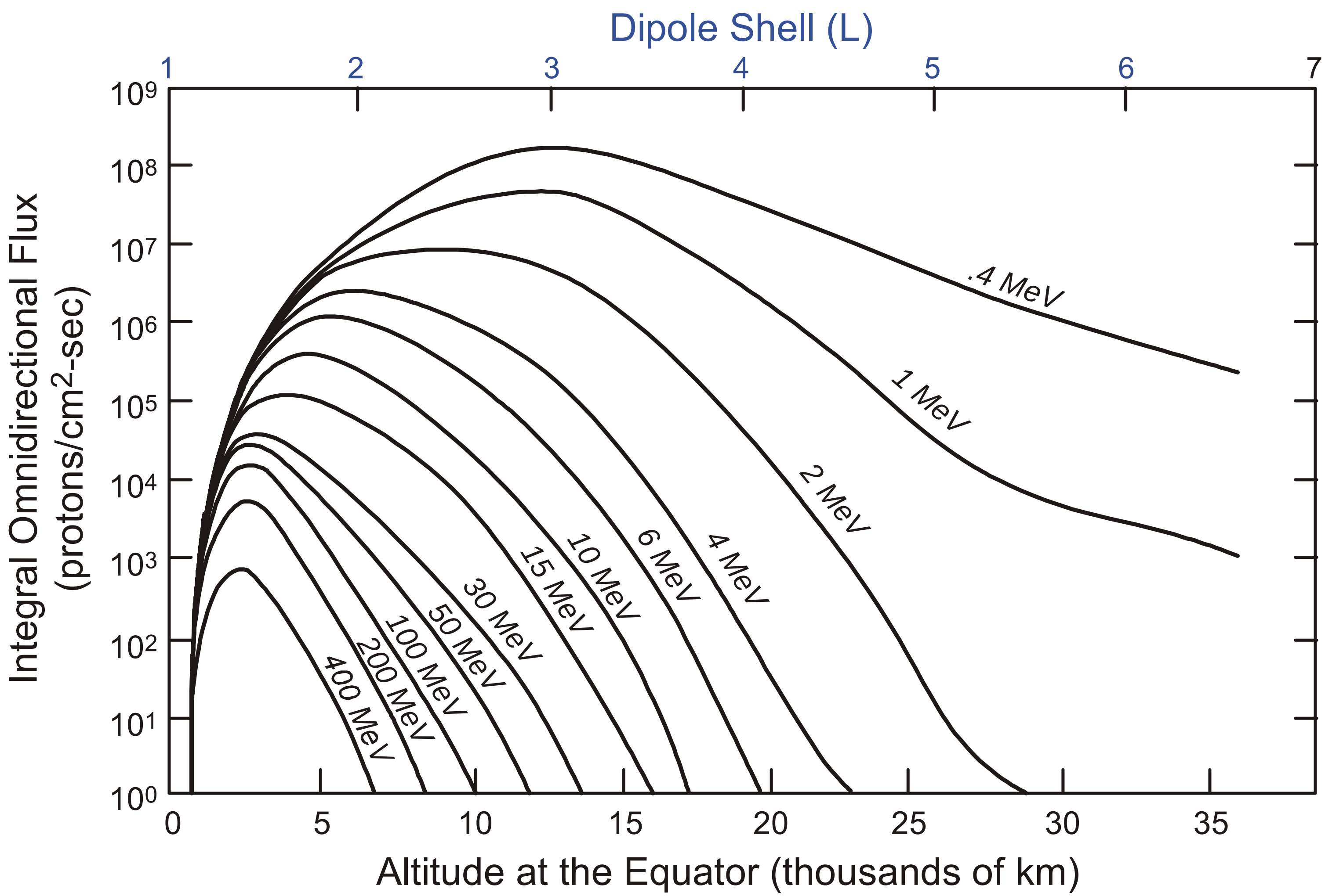
Radiation Causing “Global” Radiation Damage

- Trapped protons in radiation belts
- Trapped electrons in radiation belts
- Protons from solar flares

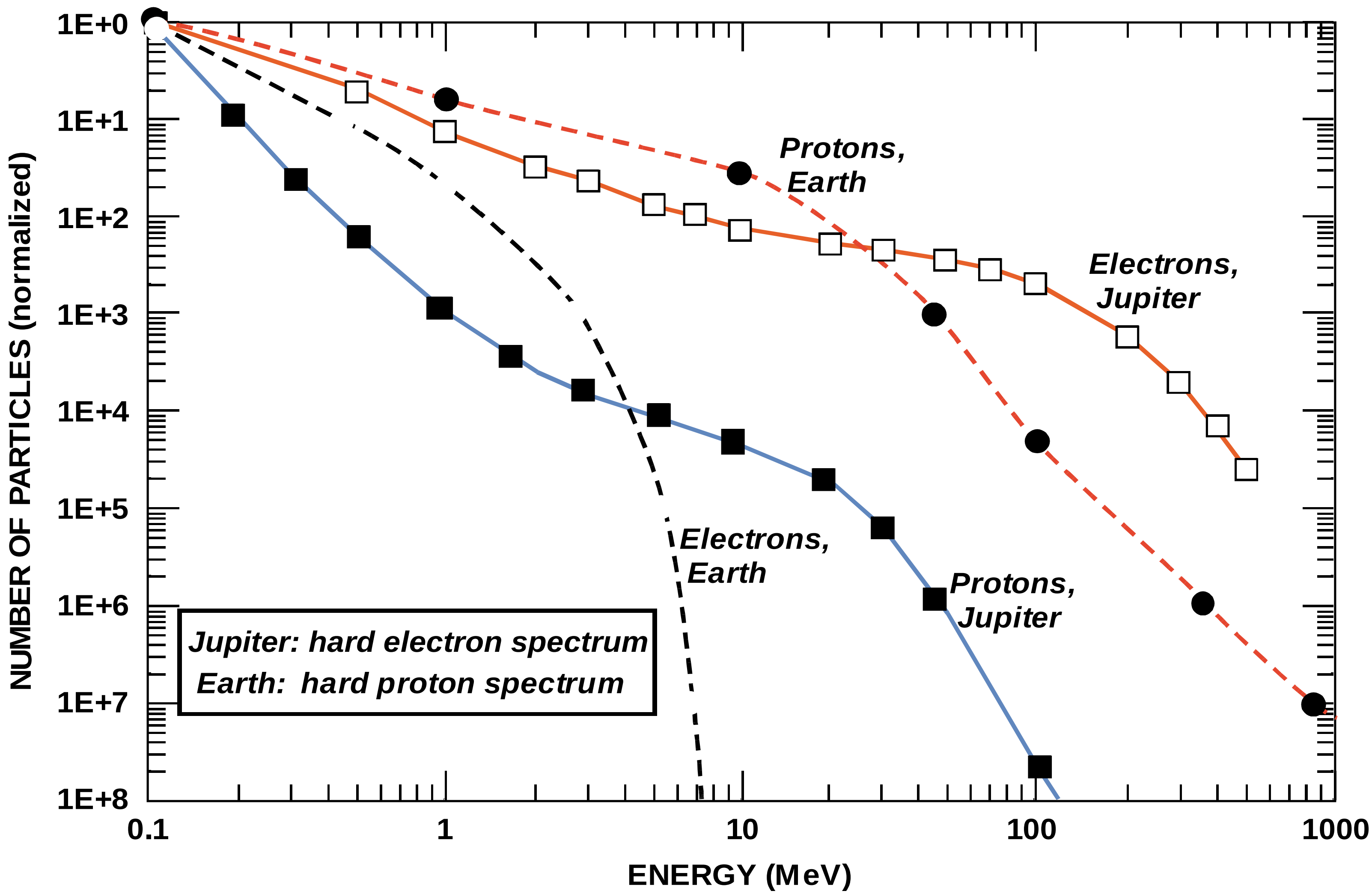
Trapped Radiation Belts around Earth



Energy Distribution in the Earth's Proton Belt



Trapped Belt Energy Distributions on Jupiter and Earth



Space Systems at JPL

Interplanetary Missions

- Jupiter and Saturn
  - Intense radiation belts
  - Very high radiation levels [> 1 Mrad(Si)]
- Mars Missions
  - Orbiters
  - Landers
- Asteroids, Comets and Solar Probes

Earth Orbiting Missions

- Typical radiation levels < 20 krad(Si)
  - Depends on altitude and inclination
  - Affected by south Atlantic anomaly
- Less margin between specified radiation environment and reality

Solar Flares

Solar Cycle Has Eleven-Year Periodicity

Solar Flares Produce Heavy Ions and Protons

- Heavy ion spectrum is less energetic than galactic cosmic ray spectrum
- Protons from solar flares are important for earth orbiting and deep space programs
  - Protons from a single flare produce fluences up to ~ 2×10^{10} p/cm^2
  - Shielding can be effective for lower energies

Solar Flare Intensity Varies Over a Wide Range

- JPL “design-case” flare usually used for specifications
- Many systems never experience a large flare

Mechanisms for Global Permanent Damage

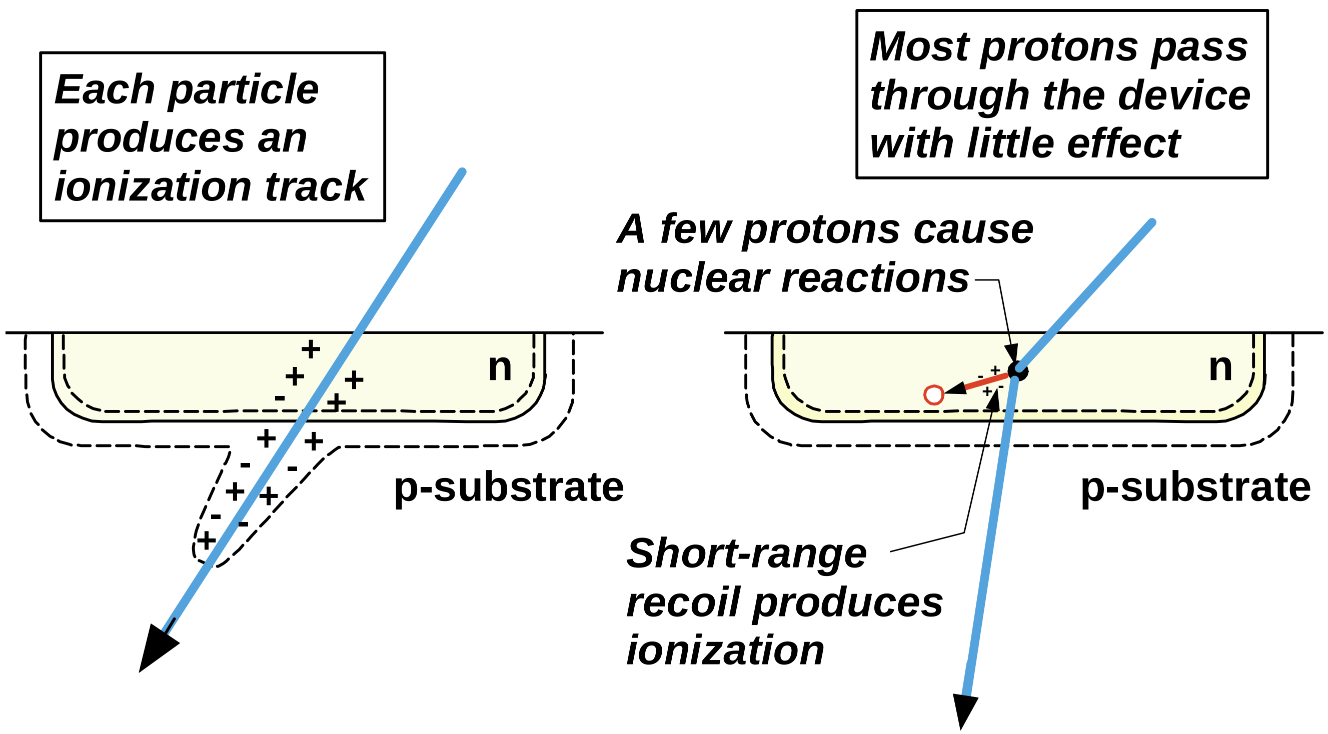
Electrons and Protons Produce Ionization in Semiconductors

- Ionization excites carriers from conduction to valence band
- Charge is trapped at interface regions
- Units: rad(material) *1 rad = 100 ergs/g of material*
- Depends on bias conditions and device technology
- Typical effect: threshold shift in MOS transistors

Displacement Damage Also Occurs

- "Collision" between incoming particle and lattice atom
- Lattice atom is moved out of normal position
- Degrades minority carrier lifetime
- Typical effect: degradation of gain and leakage current in bipolar transistors

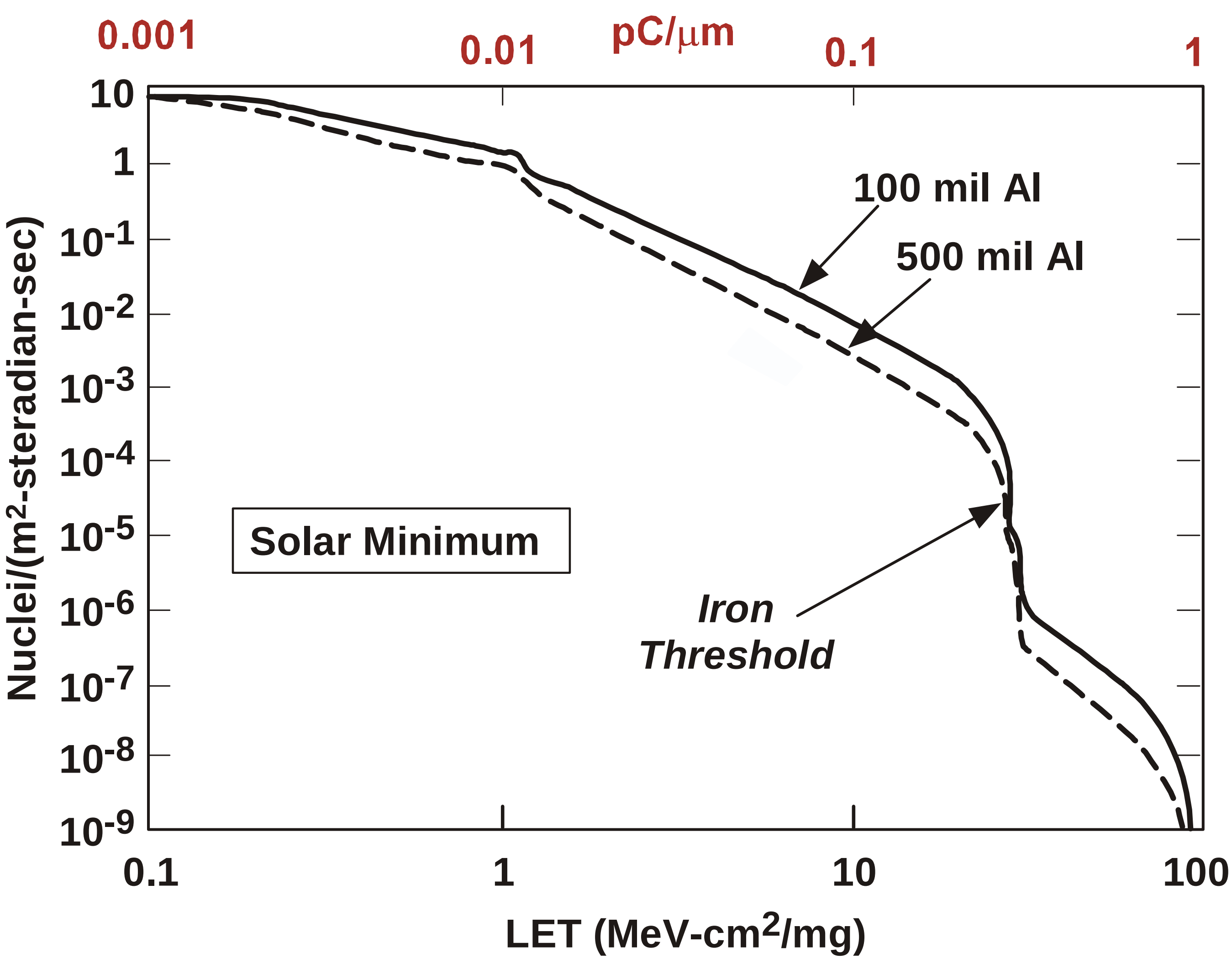
Mechanisms for Heavy Ion and Proton SEU Effects



a) Heavy Ions *(ionization by each particle)*

b) Protons *(nuclear reaction needed to produce recoil)*

Integral Cosmic Ray Spectra



SEE Sensitivity Benchmarks

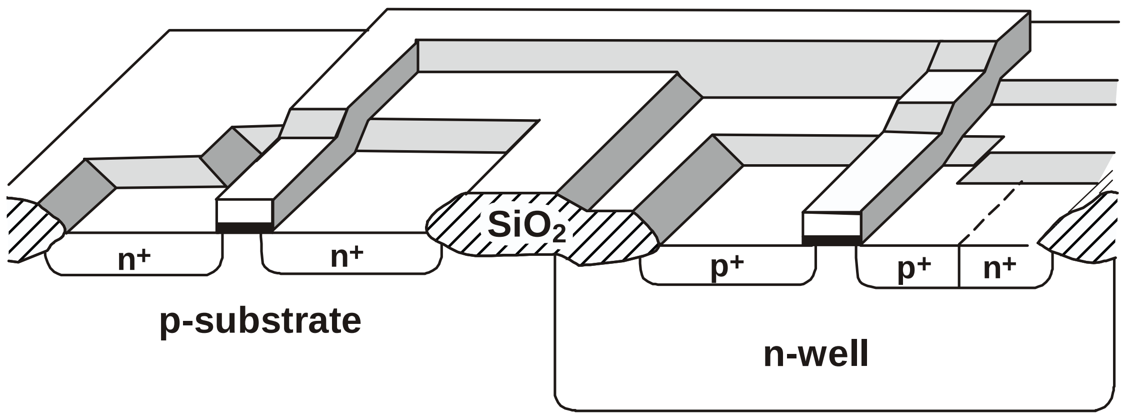
Heavy Ion Susceptibility

- Spectrum falls sharply above 30 MeV-cm^2/mg
- Effective threshold for concern is much higher, 75 MeV-cm^2/mg
  - Charge produced by ions depends on total path length
  - Increases as $1/(\cos \theta)$

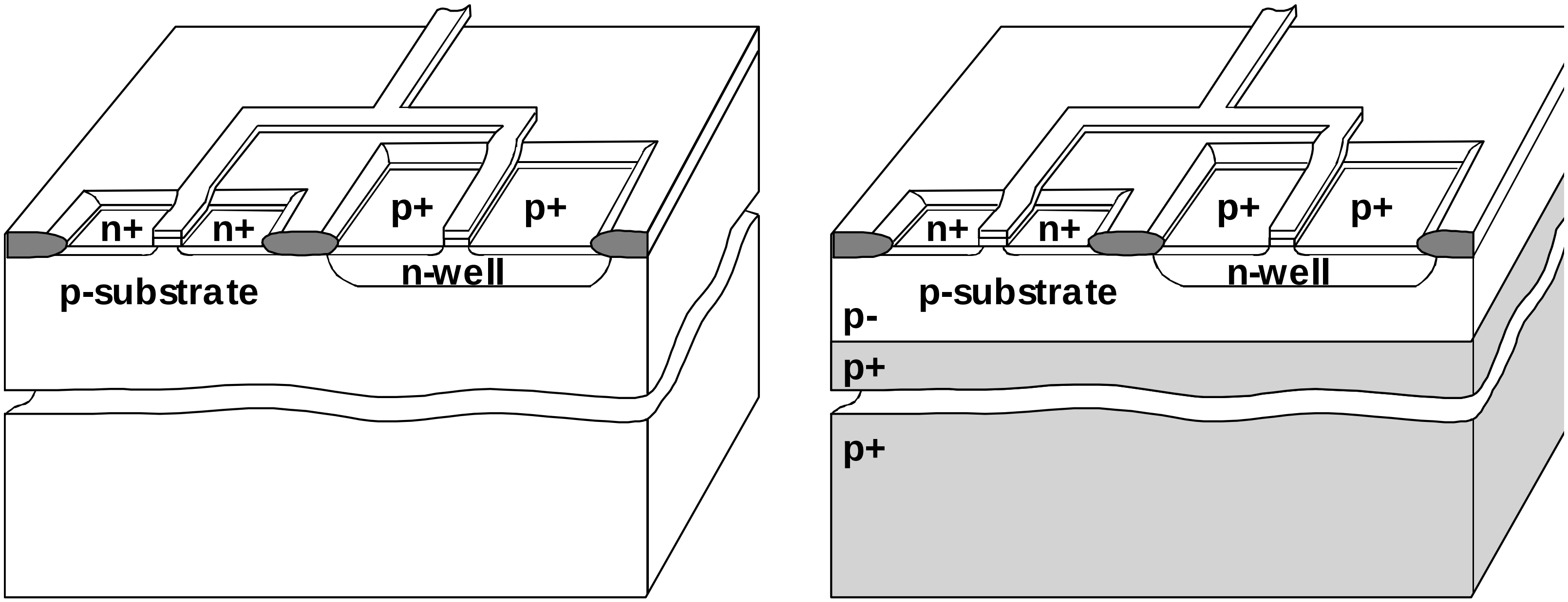
Proton Susceptibility

- Proton upset is possible for devices with LET_{th} < 15 MeV-cm^2/mg
- Proton testing should be done for all devices with thresholds below that level

CMOS Technology



Bulk and Epitaxial Substrates



Bipolar Technology

Structure of a bipolar transistor